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# DEVELOPMENT OF SHAPE ANALYSIS ALGORITHMS

FINAL REPORT

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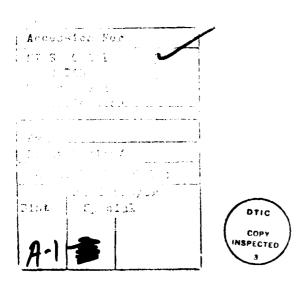July 1985

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**20. ABSTRACT (Continue on reverse side if necessary and identify by block number)**

This report summarizes the results of a four year research effort. The primary research topic addressed is automatic shape recognition of silhouettes or contours. Methods studied are Fourier descriptors, Walsh descriptors, and 2-D moments. Also the recognition of partially correct shapes are addressed. Three methods were developed to solve such problems. These methods are (1) polygonal fitting of a boundary followed by local matching of distances and angles; (2) Fourier descriptor representation of boundary segments followed by dynamic programming to match segments (dynamic programming is modified to

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allow several local optimums instead of one global optimum; and (3) recognition of time-axis scaling and matches between two partially matching waveforms using Mellin Transform techniques.

Other research topics addressed by this summary are (1) registration and segmentation of moving objects; (2) measurement and recognition using 3-D range data; (3) image compression using motion detection; and (4) precision measurements in digital images.

The research summarized in the report resulted in 5 Ph.D. Theses, 5 M.S.E.E. theses, and over 20 additional publications.

## Foreword

This final report summarizes the results of a four-year research effort undertaken by the School of Electrical Engineering at Purdue University. The primary purpose of this work has been to investigate the various aspects of shape recognition in digitized images. As indicated in detail in Section III, five Ph.D theses and five M.S.E.E. theses resulted from this research, as well as over 20 additional publications. The author is indebted to the 12 graduate students listed in Section III who provided the programming and many of the good ideas presented in these publications.

The value of the research resulting from this grant is difficult to estimate without the perspective of the future. However the results of experimental tests and the increase in interest by other investigators indicate that the global shape descriptors (especially Fourier descriptors and 2-D moments) have a future in target recognition systems and other computer visioin applications. Of particular interest are the techniques developed for partial shape recognition. These results are very new and their usefulness in practical applications remains to be seen. Although conference presentations describing these results have been made, the journal publications have not yet appeared (some have not yet been submitted). However the potential applications appear significant. The work on the Mellin Transform for scale invariant recognition of partially correct waveforms and shapes appears to have many applications in fields such as acoustic processing, radar, and video processing.

The author would like to thank Dr. Frank Kuhl of the U. S. Army ARDC for his interest, support, and research contributions to this project and Dr. William Sander of the U. S. Army Research Office for his support and assistance.

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# I. Statement of the Problem Studied

The primary research topic addressed by this effort was shape recognition; i.e., given a silhouette or contour extracted by computer from a 2-D digitized image, compare the shape to known specific shapes to recognize the unknown shape. The libraries used for comparison could be generaed by 3-D solid models, pictures of known shapes, or a generic description of a shape to be identified. During the course of this research, several methods were compared, improvements were added, and new methods were developed. Emphasis was placed on recognition of aircraft shapes. Shape recognition under three types of conditions was studied: (1) low noise, complete detailed contours; (2) noisy but complete contours; and (3) incomplete or partially correct contours.

Other related research topics were addressed during the course of this project. These topics were (1) registration and segmentation of moving objects; (2) measurement and recognition using 3-D range data; (3) image compression using motion detection; and (4) precision measurements in digital images.

## II. Summary of the Most Important Results

### A. Development of Fourier Descriptors, 2-D Moments, and Walsh Descriptors for Global Shape Recognition and the Comparison of these Methods.

All three of these shape description methods are useful for recognizing boundaries or silhouettes which have moderate to complex detail and low to moderate noise. In the Ph.D. thesis of Grogan[1], these three methods are described in detail and comparisons of the shape discrimination capabilities of each are described. In the Ph.D. thesis of Rostampour[2], improvements in the 2-D moment method are described which improve performance considerably. The results of these combined studies can be summarized as follows:

1. For recognition of low-noise, high-detail silhouettes and comparison to hundreds of possible shapes, Fourier descriptors performed the best, Walsh descriptors were faster but slightly less accurate, and 2-D moments were slightly less accurate.

2. For higher noise situations (S/N < 10 dB), the normalized 2-D moments performed the best. However, the performance of all methods tested fell off rapidly below a signal to noise ratio in the original image of 10 dB.

3. An unknown image target resolution of 64x64 pixels is required for optimum classification accuracy; a resolution of 16x16 pixels is usable but classification accuracy drops.

4. About 32 shape features must be calculated for best accuracy but moderate accuracy is obtainable with only 12 features.

5. Classification accuracy drops by 10% when 10% of the contour is incorrect and drops by 40% when 20% of the contour is incorrect.

A demonstration video tape has been produced which shows the shape classification performance of the Fourier descriptor algorithms using video imagery of commercial aircraft filmed at O'Hare airport. A description of the system used can be found in [5] and [6].

A modular shape analysis software system has been writted in Fortran 77 (some programs have also been rewritten in 'C') to allow comparison of various shape descriptors. This system has modules for library graphics generation, shape descriptor generation (Fourier descriptors, Walsh descriptors, and 2-D moments), shape descriptor normalization, redundancy reduction transformation, feature vector manipulation (to allow combinations of various features), and classification of unknown shapes.

Other publications which describe details and applications of these shape recognition techniques are [11], [15], [16], [17], [18], [19], [21], [24], and [26].

## B. Accuracy of Fourier Descriptors for Estimating Orientation of a 3-D Object from TV Images

Since the Fourier descriptor can be used to compare a complex shape with many very similar library entries, it is a good method for estimating the orientation of a 3-D object with respect to a TV camera. The method used involves storing descriptors to find the best match with an unknown. Interpolation can be used to improve the accuracy even further. In one detailed study conducted for Battelle Columbus labs [32], the orientation of an aircraft could be determined to within an error of 0.020 radians for yaw, 0.023 radians for pitch, and 0.011 radians for roll (these numbers represent one standard deviation). These results were also reported at an Army Research Office Workshop [32].

## C. Development of a Method to Estimate the Required Number and Aspect Angles of Library Entries for Recognition of a 3-D Object from any Angle.

The number and direction of viewing angles required to recognize a 3-D object depends on the object itself. If memory required or processing speed is important, it may be necessary to store a minimum number of library entries. We have developed a procedure of ordering the library entries, eliminating redundant views, and storing the entries differentially which requires less storage, is faster, and gives accurate classification results [5], [7], and [11].

## D. Recognition of Partial Contours using Polygonal Fitting and Local Matching

A method of partial contour recognition has been developed which involves matching sections of the boundary with straight line segments (polygonal matching). Emphasis is placed on speed and repeatability of the line fitting. A binary tree decomposition of the boundary is used. The features extracted are straight line distances and angle changes along the contour. A recognition algorithm has been programmed which finds the best match between the unknown and straight line contours independently of scale, orientation, and partially incorrect data. The recognition algorithm also allows feature combinations so that shapes extracted at different resolutions (which could have a different number of line segments) can still be matched [9], [27].

## E. Recognition of Partial Contours using Dynamic Programming to Match Segments Described with Fourier Descriptors.

This method involves segmenting a contour into segments and describing each segment with Fourier descriptors. When two contours are to be compared, the distances between each of their respective segment sets may be viewed as an inter-segment distance table. A dynamic programming approach for this problem has been developed which finds a path through this distance table which gives the best local matches independent of any few bad matches along the path. Thus the normal dynamic programming approach which results in a global optimum path has been modified to find a large number of local optimums independent of whether it results in a global optimum. Tests on partial aircraft contours have shown that this method works very well [31].

## F. Recognition of Partial Matches using Mellin Transform Techniques

Tracing the boundary of an object distorted by noise, obscuration, or poor segmentation produces a boundary function with an unknown scaling factor when the range is unknown. Because of this unknown scaling, we cannot use available signal processing techniques which are primarily concerned with a class of signals with identical scale factors after some normalization procedure, e.g., the methods of Fourier descriptors, moments, matched filtering, and Wiener filtering. The Mellin transform has a property which enables us to calculate these unknown scale factors. We have shown that there exists a homomorphic system which converts scale information into translation information, or the Mellin transform into the Fourier transform and this fact, in turn, enables us to use the existing signal processing techniques. Digital implementation of the homomorphic system and the Mellin transform have been studied based on the Mellin sampling theorem derived in this research and on finite dimensional function spaces, which alleviates the problem of the aliasing effect of the digital Mellin transform which is present in existing algorithms. To solve the reported problems of the Mellin transform such as lower domain emphasis, boundary effects, and a problem related to changes in amplitude of a signal, we have introduced the generalized Mellin transform and shown that, with the orthonormal Mellin transform, all these problems are alleviated.

A fast direct Mellin transform technique has been developed during the course of this research. The basic features of this approach are that two partially matching waveforms can be compared and the time-axis scaling factor which gives the best match can be calculated (useful for passive range detection) and that features can be calculated from waveforms which are invariant to time-axis scaling of the waveforms (useful for partial shape recognition and processing of acoustic signals derived from

rotating machinery of unknown speeds).

Initial partial shape recognition experiments using the Mellin Transform are given in [1], [20], and [24]. Fundamental developments in Mellin Transform theory and its application to signal processing problems is given in [4]. This work is very new and has not yet been submitted for journal publication.

## G. Algorithms for Registration and Segmentation of Moving Objects

Another project has been devoted to the analysis of sequential video frames for registration, motion detection, temporal enhancement, and moving object segmentation. A registration technique has been developed based on binarization and correlation which allows rapid sequential frame alignment. After the imagery is registered, any motion in the frame can be detection by measuring temporal variance at each point. Each moving object can then be registered and temporally enhanced by temporal median filtering. This results in sharp clear pictures of moving objects even when any single frame is noisy and blurred.

After background registration, temporal variance measurements over sequential frames are used to provide moving area masks. When sequential moving area masks are ANDed, the moving objects are segmented. Also the background surrounding the moving area mask can be used to closely estimate the background region statistics for target segmentation [2].

## H. Image Compression using Block Truncation Coding

Research has also been conducted into the coding of image data. The technique of block truncation coding has been extended to color data and an additional modification has been made which allows more accurate reconstructions and faster computation. Real-time compression of 24-bit color imagery to 2 bits/pixel with little visible degradation has been accomplished [8],[13]. This technique has also been extended so that the temporal correlation of sequential data can be used to reduce the bit rate even further[10]. This work has application in remote reconnaissance, image data storage, and teleconferencing.

## I. Precision Target Location using Fourier Descriptors

The use of Fourier descriptors for shape recognition was applied to another problem of interest to photogrammetrists. In a separate grant by the U. S. Army Research Office (DAAG29-81-K-0063), the Fourier descriptors and 2-D moments developed under this grant were applied to the problem of precision measurements in digitized imagery. It was found that pointing accuracies better than 1/10 of a pixel can be obtained in many situations (e.g., pointing at the center of a cross shaped object in a noisy background). This results of this work are reported in the Final Report (Sept. 1984) and in the references [12] and [32].

## J. Automatic Interpretation of Range Data

The aim of this research program is to develop methods for recognizing objects from their range maps. During the past, shape recognition algorithms were based mostly on silhouette and/or line representation of objects. However, silhouettes and lines cannot be extracted with great reliability because of the difficulties caused by reflectance variability, shape and shadow effects. With range data, boundaries and edges are defined as range and range gradient discontinuities, these being immune to the problems with reflectance data.

In our program we devised strategies in which objects are characterized on the basis of the orientation of their major surfaces; these orientations being obtained by fitting planes and other regular curved surfaces to measured range maps. We have also developed a new scheme for extracting edges from the range data. This scheme consists of first constructing a synthetic image from the range map in which the gray level at each point is proportional to the orientation of the local surface normal and then applying a reflectance data edge detector to this synthetic image. In [21] we show examples of both the surface extraction and the detection of edges with the new procedure.

## III. Publications and Technical Reports

The following list of publications represents work resulting entirely or in part from this grant. This section also serves as the list of references for Section II.

**Theses Completed by Graduate Research Assistants** (All from School of Electrical Engineering, Purdue University, West Lafayette, Indiana, Prof. O. R. Mitchell, Thesis Advisor).

[1]    Timothy A. Grogan, "Shape Recognition and Description: A Comparative Study," Ph.D Thesis, August 1983.

[2]    Abdolrahim Rostampour, "Algorithms for Image Registration, Moving Object Detection and Identification," Ph.D. Thesis, December 1983.

[3]    Mark L. Akey, "Precision Feature Location in Digitized Imagery," Ph.D. Thesis, May 1985.

[4]    Semoon Goh, "The Mellin Transformation: Theory and Digital Filter Implementation," Ph.D. Thesis, May 1985.

[5]    D. J. Charpentier, "Three-Dimensional Shape Recognition using Fourier Descriptors and Multi-Dimensional Chain Codes," M.S.E.E. Thesis, Dec. 1981.

[6]    J. P. Gifford, "Classification of Three-Dimensional Partial Shapes using Local Shape Descriptors," M.S.E.E. Thesis, May 1982.

[7]    M. E. Glenn, "Fourier Descriptors of Two and Three-Dimensional Objects," M.S.E.E. Thesis, Aug. 1982.

[8]    M. D. Lema, "Absolute Moment Block Truncation Coding and its Application to Still Color Images," M.S.E.E. Thesis, Aug. 1982.

[9]    Farzin Davallou, "Recognition of Three-Dimensional Objects from a Random Viewing Angle," M.S.E.E. Thesis, May 1984.

[10]   Maximo Lema, "Theory and Applications of Absolute Moment Block Truncation Coding of Video Data," Ph.D. Thesis, August 1984.

**Other Publications Resulting from this Research** (Those marked with an asterisk are related publications but were not produced under this ARO grant.)

[11] F. P. Kuhl, O. R. Mitchell, M. E. Glenn, and D. J. Charpentier, "Global Shape Recognition of 3-D Objects using a Differential Library Storage," *Computer Graphics and Image Processing,* Vol. 27, pp. 97-114, 1984.

[12]* E. M. Mikhail, M. L. Akey, and O. R. Mitchell, "Detection and Sub-Pixel Location of Photogrammetric Targets in Digital Images," *Photogrammetria,* Vol. 39, pp. 63-83, 1984.

[13] M. D. Lema and O. R. Mitchell, "Absolute Moment Block Truncation Coding and its Application to Color Images," *IEEE Trans. on Commun.* Vol. COM-32, pp. 1148-1157, Oct. 1984.

[14] F. P. Kuhl, C. R. Giardina, O. R. Mitchell, and D. J. Charpentier, "Three-Dimensional Object Recognition using N-Dimensional Chain Codes," *Southcon/82 Proceedings,* Orlando, Florida, March 23-25, 1982.

[15] O. R. Mitchell, F. P. Kuhl, T. A. Grogan, and D. J. Charpentier, "A Shape Extraction and Recognition System," *Southcon/82 Proceedings,* Orlando, Florida, March 23-25, 1982.

[16] C. R. Giardina, F. P. Kuhl, T. A. Grogan, and O. R. Mitchell, "A Spatial Domain Walsh Feature Set," *Trans. of the Twenty-Eighth Conf. of Army Mathematicians,* U. S. Army Research Office Report No. 83-1, pp. 397-408, Bethesda, Maryland, June 28-30, 1982.

[17] O. R. Mitchell, A. P. Reeves, and T. A. Grogan, "Algorithms and Architectures for Global Shape Analysis in Time-Varying Imagery," *SPIE Proceedings 360,* Robotics and Industrial Automation, San Diego, Aug. 24-27, 1982.

[18]* A. P. Reeves and O. R. Mitchell, "An Image Analysis System for 3-D Objects in Real Time," Eleventh Workshop on *Applied Imagery Pattern Recognition,* College Park, Maryland, Sept. 28-29, 1982.

[19] H. J. Siegel, O. R. Mitchell, and L. J. Siegel, "PASM: A Large-Scale System for Studying Parallel Image Processing," *GOMAC-82* (Government Microcircuit Applications Conference), Orlando, Florida, Nov. 2-4, 1982.

[20] T. A. Grogan and O. R. Mitchell, "Partial Shape Recognition using Fourier-Mellin Transform Methods," *Topical Meeting on Signal Recovery and Synthesis with Incomplete and Partial Constraints*, Incline Village, Nevada, Jan. 12-14, 1983.

[21] F. P. Kuhl and O. R. Mitchell, "Automated Target Recognition," *Conf. on Artificial Intelligence Proceedings*, Rochester, Michigan, pp. 533-542, April 26-27, 1983.

[22] D. L. Tuomenoksa, G. B. Adams, H. J. Siegel, and O. R. Mitchell, "A Parallel Algorithm for Contour Extraction: Advantages and Architectural Implications," *Computer Vision and Pattern Recognition CVPR83*, Arlington, VA, June 19-23, 1983.

[23] A. P. Reeves, M. L. Akey, and O. R. Mitchell, "A Moment Based Two-Dimensional Edge Operator," *Computer Vision and Pattern Recognition CVPR83*, Arlington, VA, June 19-23, 1983.

[24]* O. R. Mitchell and T. A. Grogan, "Global and Partial Shape Discrimination for Computer Vision," *Optical Engineering*, Vol. 23, pp. 484-491, Sept. 1984.

[25]* E. M. Mikhail, M. L. Akey, and O. R. Mitchell, "Detection and Subpixel Location of Photogrammetric Targets in Digital Images," *Specialist Workshop on Pattern Recognition in Photogrammetry*, Graz, Austria, Sept. 27-29, 1983.

[26]* O. R. Mitchell and T. A. Grogan, "Shape Descriptors of Object Boundaries for Computer Vision," *SPIE Proceedings 449*, Intelligent Robots: Third International Conference on Robot Vision and Sensory Controls, Vol. 2, pp. 685-692, Cambridge, MA, Nov. 7-10, 1983.

[27] F. Davallou, O. R. Mitchell, and F. P. Kuhl, "Recognition of Partially-Distorted Contours using Local Features," *1984 Conf. on Intelligent Systems and Machines*, Rochester, Michigan, April 24-25, 1984.

[28]* M. L. Akey and O. R. Mitchell, "Detection and Sub-Pixel Location of Objects in Digitized Aerial Imagery," *Seventh International Conference on Pattern Recognition Proceedings*, Montreal, Canada, Vol. 1, pp. 411-414, July 30 - Aug. 2, 1984.

[29] O. R. Mitchell, "Shape Recognition Methods," *Artificial Intelligence and Robotics Symposium*, American Defense Preparedness Association, Indianapolis, Indiana,

Sept. 12-13, 1984.

[30]  H. S. Yang, K. L. Boyer, and A. C. Kak, "Range Data Extraction and Interpretation by Structured Light," *Conf. on Artificial Intelligence Applications*, Denver, Colorado, Dec. 5-7, 1984.

[31]  J. Gorman, O. R. Mitchell, and F. P. Kuhl, "Partial Shape Recognition using Fourier Descriptors," *1985 Conf. on Intelligent Systems and Machines*, Rochester, Michigan, April 23-24, 1985.

[32]  O. R. Mitchell, D. Andrisani, A. P. Reeves, and F. P. Kuhl, "Lead Angle Prediction for Maneuvering Aircraft Targets," *Army Research Office Workshop on Assessment of Analytic Methods for Target Acquisition and Tracking*, Fort Belvoir, Virginia, Feb. 13-15, 1984.

## IV. Scientific Personnel Supported by this Project:

Faculty:
>   Prof. O. R. Mitchell
>   Prof. A. C. Kak

Graduate Research Assistants (Degrees Received shown following name):
>   T. A. Grogan (Ph.D.)
>   D. J. Charpentier (M.S.E.E.)
>   J. P. Gifford (M.S.E.E.)
>   M. E. Glenn (M.S.E.E.)
>   M. D. Lema (M.S.E.E. and Ph.D.)
>   A. R. Rostampour (Ph.D.)
>   R. L. Stirling
>   F. Davallou (M.S.E.E.)
>   S. Goh (Ph.D.)
>   J. W. Gorman
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>   M. L. Akey (Ph.D.)

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